An Analysis of the Potential Environmental Remediation and Economic Benefits Anaerobic Digesters Offer to the Dairy and Swine Industries: A Comparison of China and the U.S.

An Analysis of the Potential Environmental Remediation and Economic Benefits Anaerobic Digesters Offer to the Dairy and Swine Industries: A Comparison of China and the U.S.

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Abstract

The purpose of this research is to investigate the environmental remediation and energy potential of anaerobic digesters on pig and dairy farms and to demonstrate how incorporating those benefits into a cost-benefit analysis would make biodigester projects more financially feasible. By assigning dollar values to the emissions and water pollution avoided by this technology, I sought to update the traditional cost-benefit analyses (CBAs) to demonstrate that this technology is more widely applicable. The study took place In the Lake Champlain Drainage Basin, USA and the Lake Tai Drainage Basin, China. Dairy and pork production are high density endeavors and produce large quantities of waste which make them ideal candidates for biodigesters. Using standard emissions estimates and gas production rates from past research and from the current Cow Power Program in Vermont, the methane and nitrous oxide emissions averted by adding a biodigester to a particular farm were estimated. Additionally, using past research, the total nitrogen and phosphorous collected by the biodigesters and diverted from becoming classified as non-point source pollution was calculated, valued, and incorporated into a CBA tool. The results from this study show that the incorporation of environmental benefits in a CBA for Green Mountain Dairy increased profitability by 60% and reduced the payback period by two years. Overall, projects that include environmental benefits are 72% more profitable and the payback period is cut in half. Further development of the CBA tool is needed to strengthen results. This study points to the need for more experimental data on the environmental benefits of biodigesters.

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Chapter I

Introduction

This thesis research proposes to examine the potential of anaerobic digesters to remediate environmental pollutants from dairy and swine operations and, using comprehensive economic modeling, to challenge previous analyses of financial viability. A central goal of this thesis project is to establish and demonstrate the link between improved water quality and biodigester implementation. Additionally, I intend to investigate the full scope of collateral environmental benefits that this technology may provide, along with their estimated economic value. These benefits include, but are not limited to, the potential for emissions reductions, energy production, additional revenue sources, species conservation, and human health. I also hope to show that this technology remains economically and environmentally salient at different scales and in different cultural situations. The results of the study will be valuable for those concerned with incentivizing and developing policies supporting environmentally sustainable agricultural practices in the dairy and swine industries as well as those interested in implementing biodigester technology.

Background

Anaerobic digestion is the process by which organic materials are broken down in the absence of oxygen. Industrial biodigesters break down and separate organic waste materials into usable biogas (CH_4) and nitrogen rich compost which can be used as a fertilizer for crops. The development and implementation of this relatively simple technology reduces water pollution from agricultural and industrial practices, reduces methane emissions, supplements natural gas and/or electricity needs to local communities, and provides farmers with organic fertilizer with potential resale value. Biodigesters can be used in most situations where organic materials are by-products, but they have been shown to be particularly well suited to dairies and piggeries which produce reliable quantities of animal waste in an enclosed or limited area (U.S. Environmental Protection Agency, 2012).

Anaerobic digesters have the potential to become an important sustainable technology utilized around the world because biodigester technology is not overly technical and easily adaptable to different capacities and scales of operation. In spite of this, biodigesters have not been widely adopted by farmers (Key & Sneeringer, 2011). This is primarily because the costs of constructing biodigesters, up to this point, have often outweighed the financial benefit to the operator (Key & Sneeringer, 2011). However, these cost benefit analyses (CBAs) do not consider and value the full range of environmental and social benefits biodigesters could contribute to economies.

To date, much of the available research concerning the feasibility of biodigester projects includes analysis of the financial viability surrounding construction, maintenance, and the potential for income generated or saved through natural gas production. In a study of small scale biodigester implementation in South Africa, researchers assessed the financial and economic feasibility by conducting a survey of household income and assets for 120 households in the poor community of Okhombe (Smith, Goebel, & Blignaut, 2014). Additionally, they made observations on the social acceptance and the impact on family dynamics from four biodigesters previously installed at no cost by an NGO as a pilot project. They concluded that biodigesters were not a financially feasible option for individual family investment, but found that they did benefit the local economy as a whole. The economic advantages biodigesters imparted included less time spent cooking and collecting firewood, improved health, and increased lifespan (Smith et al., 2014). Although some environmental benefits, such as emissions reduction and preservation of indigenous trees, were listed as a potential additional benefit, these benefits were not assigned a monetary value and therefore played no role in the cost benefit analysis.

Assigning a dollar value to ecosystem services is complicated, inexact and even controversial, which has led many researchers to exclude them from cost benefit analyses (King & Mazzotta, 2000). However, because imperatives for environmental stewardship and greenhouse gas (GHG) emission reductions are now central global issues, these services must be fairly represented in any cost benefit analysis. In a study conducted in the Minnesota River Basin, researchers assigned different dollar values (low, medium and high) to the increases in ecosystems services that would result from retiring agricultural land along the Minnesota River (Johnson, Polasky, Nelson, & Pennington, 2012). The researchers assumed land retirement values of 2%, 8%, and 30% and correlated those to varying returns available from various agricultural production activities (Johnson et al., 2012). The research results showed that when agricultural production returns were low and ecosystems services gains were high (30%), land retirement generated the most economic benefit. By contrast, low returns for ecosystem services at high (30%) land retirement values on land that delivers high agricultural returns generated the least economic benefit (Johnson et al., 2012). The value of this study is that it attempts to find optimal balance points between land retirements that yield ecosystem benefits and reductions in farm income. The study concluded that agricultural returns had a greater effect on behavioral outcomes than either ecosystem effects or land retirement values (Johnson et al., 2012). This research underscores the need to promote understanding of ecosystem effects and, to the extent possible, for standardizing ecosystem valuation when assessing land use scenarios, as it is clear that faulty or contrived values will greatly skew results. However, there are several key issues that are ignored in this research. First, and acknowledged by the authors, alteration in land and nutrient management strategies may have similar environmental benefits and require less land to be retired resulting in less potential income loss. Secondly, with little or no change to the status quo, agricultural lands, available water resources, and, eventually, climate will become increasingly inhospitable and agricultural production will suffer immensely, nullifying the usefulness or any cost-benefit analysis that fails to include environmental impacts.

One of the major environmental and economic benefits of biodigesters is the potential mitigation of water pollution from animal wastes. The primary pollutants that affect water quality are nitrogen (N), phosphorous (P), sodium chloride (NaCl), and harmful microorganisms; these processes are described by Ritter & Shirmohammadi (2000). Animals kept at high densities produce excess concentrations of N and P and cause eutrophication in open waterways which results in algae growth, depletion of dissolved oxygen, turbidity, and overall degradation of water quality. Nitrogen in water bodies is readily converted to ammonia (NH_3) which is, even at very low concentrations, toxic to fish and other species. N and P fuels algae growth which strips water of dissolved oxygen. Dissolved oxygen is essential to the survival of fish and other aquatic species;

therefore, drops in oxygen concentration often cause massive die-offs and a reduction in genetic diversity of local species. An estimated 50 -70% of US surface waters are being negatively impacted by agricultural practices from animal sources and cultivated croplands, and, in Europe, research points to high density livestock production as one of the primary causes of NH_3 contamination (Ritter & Shirmohammadi, 2000). In addition to nutrient contamination, the microorganisms found in animal manures can cause about 150 different diseases, both bacterial and viral, that affect human and animal health. Of particular concern to human health is fecal coliform bacteria and protozoa cryptosporidium (Ritter & Shirmohammadi, 2000).

Runoff from animal feed lots and seepage from inadequate manure storage structures are the primary mode of contamination from animal facilities (that is, prior to any secondary uses such as fertilizers) (Ritter & Shirmohammadi, 2000). Nutrients and microorganisms travel through soils at different rates and pollute at different concentrations based upon external factors like precipitation, soil type, and vegetation cover (Ritter & Shirmohammadi, 2000). Large animal facilities (1000+ animals) are regulated in the U.S by the Clean Water Act and required to effectively manage waste to avoid water pollution, and facilities with 300 or more animals must have a permit if they are going to discharge waste water (Ritter & Shirmohammadi, 2000). However, this still leaves the majority of dairy and hog farms below the threshold for regulation (USDA NASS, 2012).

Biodigesters have the potential to reduce water pollution from excess nutrients and microorganisms. There is a gap in the research surrounding this topic however. A study in Northern Italy, focused on mitigating the environmental impacts of dairy farms through anaerobic digesters, concluded that the positive effects biodigesters had on freshwater eutrophication were negligible (although they found a reduction in marine eutrophication) (Battini, Agostini, Boulamanti, Giuntoli, & Amaducci, 2014). However, according to their analysis, the main source of the eutrophication was from feed crops purchased from other farms and from fertilizing fields on site, the latter of which was not described in the article. They determined the quantity of P and N leaching on site by subtracting the amounts of P and N crops could potentially absorb from the total amount of P and N applied (Battini et al., 2014). A detailed description of their field management plan was not supplied, but is essential to determine the validity of their results; issues of timing, crop type, soil type, fertilizer application techniques, soil conservations strategies, and many other considerations determine the amount of P and N that leach into water systems (Ritter & Shirmohammadi, 2000). Research presented in the text "Agricultural Nonpoint Source Pollution" determined that that aboveground or lined manure containment structures (which would be analogous to containment for a biodigester) effectively eliminate leaching of ammonia (NH_3), Nitrates (NO_3), and other contaminants into waterways (Ritter & Shirmohammadi, 2000). Furthermore, and also not considered in Battini et al. (2014), due to the heat generated during anaerobic decomposition, biodigesters eliminate most pathogens which also degrade water quality (Key & Sneeringer, 2011). It seems to follow that if biodigesters were a more accessible technology, and given the multitude of environmental and financial benefits that accrue, smaller hog and dairy farms (those currently not required to have discharge permits) would be more likely to adopt this technology and the net reduction of nutrients entering water systems would be significant.

Emissions reduction is another environmental benefit biodigesters provide. Emissions from animal manure include ammonia gas (NH3), volatile organic compounds (VOCs), particulate matter, and the potent greenhouse gasses (GHGs) methane (CH_4) and nitrous oxide (N_2O) which have, respectively, 34 and 298 times the global warming potential of carbon dioxide (CO_2) (Cuéllar & Webber, 2008). A study conducted by the Duke University Nicholas Institute on animal manure management in California estimated that if all dairy farms in California adopted biodigesters where the technology is feasible (>500 head of cattle), methane emissions would be reduced by 92% or the equivalent of 7.7 teragrams (Tg) of CO2 (1Tg= 1 million metric tons) (Owen, Kebreab, & Silver, 2014). They also found that, compared to other closed manure containment structures, biodigesters emitted 10% less CH_4 gas and N_2O per head/day measured in grams/CO_2e (Owen et al., 2014). How exactly the researchers determined feasibility is not explicitly discussed in this paper; however, the authors set the minimum herd count to 500 or more head, which includes about 900 farms in California (Owen et al., 2014). Much of this determination seems to be based on the costs of building and maintaining large energy plants that would allow collected biogas to feed back into the grid or convert to electricity (Owen et al., 2014).

The energy potential of the bio-gas generated from biodigesters is significant. The gas can be used for cooking, heating, and electricity on site, or be converted to compressed natural gas (CNG) for broader use (Cuéllar & Webber, 2008). Cuéllar and Webber calculated the total generation energy potential of all animal units (AU)(1 unit = 1000lbs of animals) in the United States to be between 68.0 and 108.8 billion kWh (depending on biodigester efficiency) or 1.8-2.9% of the yearly energy consumption in the US (Cuéllar & Webber, 2008). Cuéllar and Webber estimate that if the electricity generated was used to replace the energy generated from coal burning power plants, annual CO_2 emission would be reduced by 3.9 +/- 2.3% (39.9 million metric tons – 157.5 billion kg CO2 based on efficiency of digester and emissions from coal plants) (Cuéllar & Webber, 2008). Of course this research only estimates the potential energy generation from biodigesters, not actual results.

The state of Vermont, as of 2005, has initiated a "Cow Power" energy program that feeds energy generated from biodigesters on dairy farms into the main grid (Wang, Thompson, Parsons, Rogers, & Dunn, 2011). During the time of the research, six dairy farms were participating in the energy program and were reliably supplying a significant portion of household energy to 4,606 homes in Vermont (Wang et al., 2011).

There are many other benefits that biodigesters provide to farms, families, and the environment. For example, although application of manures as fertilizers requires more soil testing and nutrient management planning than chemical fertilizers, soils that have been fertilized using organic manures consistently have higher levels of carbon (C) and lower field emissions than those supplemented with synthetic fertilizers (Owen et al., 2014). In addition, species and genetic conservation is a huge benefit that biodigesters could provide by reducing water pollution and die-offs due to eutrophication and oxygen depletion (Key & Sneeringer, 2011).

There are also social benefits that biodigesters impart to owners. In the study conducted in South Africa, researchers calculated that the adoption of biogas as a cooking fuel would reduce indoor air pollution by 65% percent (Smith et al., 2014). This has significant implications in China as the majority of rural households still use charcoal briquettes as cooking fuel, which have many proven negative health effects including lung cancer, impaired immune systems, and even arsenic poisoning in some regions (Zhang & Smith, 2007).

By furthering the understanding of the appropriate implementation of this technology and incorporating the environmental benefits of anaerobic digesters into economic models, they should, potentially, be reconsidered as a financially and economically viable option for small and medium scale farms. This will inform government organizations concerned with incentivizing sustainable farming practices and reducing nonpoint source (NPS) pollution, justifying policies to reallocate government funds to smaller projects.

Animal Type

The amount of manure and the nutrient content of that manure varies greatly between species of farm animal (Haering, Evanyl, & Abaye 2006). What animals are fed, how they are managed, what their bedding is, and other variables also affects both the amount of and nutrients found in manure (Haering, et al., 2006). Dairy cattle and swine are the focus of this study. This is because they are commonly farmed in both China and the United States, are kept at relatively high densities, and the majority of research surrounding biodigesters has been conducted on swine and dairy farms.

Dairy cattle produce more manure waste per animal unit (AU) than any other common farm animal (Haering, et al., 2006). One AU (1000lbs or about 0.74 of a dairy cow) produces on average 15.24 tons of manure per year (Haering, et. al., 2006). The large amount of waste that can be consistently collected and fed into a biodigester paired with a large dairy operation in the US has most likely contributed to the pairing of biodigester technology and the dairy industry. In addition, the fact that the manure is relatively liquid makes it easier to utilize in a biodigester (Haering, et. al., 2006). The average N and P profile of dairy manure is about 28 pounds of N and 19 pounds of P per 1000 gallons of manure (Haering, et. al., 2006). Therefore, the average dairy cow produces 853 pounds of N and 579 pounds of P per year; extrapolating from that figure to a farm with several hundred or even one thousand cows, it is easy to imagine how the nutrient load on even one farm could overwhelm the carrying capacity of an ecosystem.

Biodigester use on pig farms is also well established and has been shown to reliably produce biogas, reduce emissions, and improve water quality (Martin Jr., 2002). Although pigs produce less manure per AU, the levels of N and P are actually higher per 1000 gallons of manure (Haering, et. al, 2006). One AU of swine for meat production (about 9.09 animals) produces about 14.69 tons of manure per year (Haering, et. al., 2006). The manure contains 40 pounds of N and 37 pounds of P per 1000 gallons of manure which equals 1175 pounds of N and 1087 pounds of P per AU per year (Haering, et. al., 2006). The N and P levels in pig manure are higher than all other common high volume farm animals (Horses, layers, broilers, turkeys, dairy) (Haering, et. al., 2006). This is an especially big problem for China as a recent report found that 50% of the world's farmed pigs are raised and eaten in China (Schneider & Sharma, 2014).

Areas of Study

This study focused on the Lake Champlain Drainage Basin in the state of Vermont, U.S.A, and the Lake Tai Drainage Basin in the Jiangsu province of China. The two regions are sufficiently different to strengthen claims that biodigesters are relevant in diverse situations.

Vermont is an ideal area for conducting research because functioning biodigesters and the surrounding utility infrastructure is already in place. The Vermont Agency of Natural Resources has identified discharges from farmsteads and agricultural production areas as the primary threat to water quality in Lake Champlain (Vermont Agency of Natural Resources, 2014). With the introduction of the Cow Power program, it is relevant to determine if: 1) nutrient leaching from farms currently participating in the program has significantly decreased and 2) expanding the program to include smaller dairy and hog farms would further reduce nutrient leaching. Furthermore, data on the financial feasibility of the program, available government subsidies and aid, and energy generation makes this an ideal source of information that can be used to evaluate the potential success of other biodigester projects.

The second area included in the study is the Lake Tai Basin in the Jiangsu province of China. Lake Tai is the third largest lake in China and supports intensive agricultural and industrial activity as well as providing drinking water for a densely populated region (Reidsma et al., 2012). This area has been experiencing increasingly severe pollution sine the 1980's but in 2007, the region gained international attention with an algae bloom that covered the entire lake at a depth of several dozen centimeters and left millions without a source of clean tap water (Liang & He, 2012). Since then, the algae bloom has been a yearly event (Liang & He, 2012). Although steps have been taken by the Chinese government to regulate and reduce pollution, a significant amount of contamination can be linked to agricultural practices in the area (Reidsma et al., 2012).

Municipal biodigesters in agricultural regions around Lake Tai could reduce nutrient contamination and provide additional sources of energy and fertilizer for local residents.

Hypotheses and Specific Aims

In light of the background research, it is pertinent to investigate the possibility of expanding the application of biodigester technology to medium and small scale farms in the US and in China as a means for pollution reduction and energy generation. As environmental benefits are incorporated into an economic feasibility model, the goal is to demonstrate a shift in the cost-benefit analysis that more accurately represents the contributions and functions of biodigesters. Additionally, the CBA worksheet will be a the platform for a tool that will not only aid in the decision process of potential biodigester projects, but will also be useful and easily accessible to assist those interested in nutrient management planning. Assigning an estimate of the price of phosphorous and nitrogen will contribute to the regulation and general understanding of nonpoint source pollution. The research questions have sparked the following hypotheses:

- The potential cumulative effect of reduced watershed pollution attributed to biodigesters will increase the economic justification for initiating and expanding biodigester projects.
- The estimated monetary value assigned to one ton of Phosphorous will have a significant effect on the bottom line on cost benefit analysis of a biodigester project.

- The estimated monetary value assigned to one ton of Nitrogen will have a significant effect on the bottom line on cost benefit analysis of a biodigester project.
- The potential NH_4 and N_2O emissions avoided by expanding or adopting biodigester technology will significantly increase the economic justification for initiating and expanding biodigester projects.
- Biodigesters represent an economically justifiable method of reducing lake eutrophication around the Lake Tai Basin, China.
- With the inclusion of environmental benefits in a cost benefit analysis, it will prove financially feasible and economically justifiable for smaller dairy and hog farms to participate in the "Cow Power" program in Vermont, USA.

In addressing these hypotheses I will also be able evaluate the ancillary hypothesis that biodigesters can significantly contribute to achieving certain millennium development goals in China and in the US.

Chapter II

Methods

Participant Recruitment and Site Selection

I chose to include two locations that face serious eutrophication problems in large economically crucial freshwater bodies that are familiar with biodigesters technology but which, in almost every other way, are completely different. The hope is that this difference will demonstrate the broad applicability if this technology.

Vermont and Green Mountain Dairy

There are currently twelve farms participating in the Cow Power program launched by Vermont's electric utility company Green Mountain Power (Green Mountain Power, 2004). Only farms located in the Lake Champlain Drainage Basin were asked to participate in the study. All farms were contacted by phone and e-mail and asked to fill out a basic survey regarding their farm and biodigester operation (See Appendix 1 for survey questions). Unfortunately, only one farmer responded to inquiries and agreed to a site visit, Mr. Bill Rowell of Green Mountain Dairy. Although a wider range of independent variables and interview subjects would have unquestionably benefited this study, the comprehensive data and information provided by Mr. Rowell was adequate to serve as an example of a changing CBA.

Green Mountain Dairy is classified as a Large Farming Operation (LFO) and, dairy and cropland included, occupies 1500 acres spanning four different towns in

Vermont. The dairy houses about 1,800 Holstein cows at varying stages of development and lactation cycles. The cows are fed a high starch diet of grains and protein and are not put out to graze at any time during the year. The biodigester on this farm was the third to be built and incorporated into the Vermont Cow Power Program in 2007. The biodigester is a mixed plug flow system constructed by DVO Incorporated with a hard top covering the manure pit to help insulate the digester in colder climates (DVO Incorporated, 2015). The manure enters a 16ft deep pit and spends 21 days in the digestion process before it is run through a solids separator. Dry material is available for bedding on site or for sale to other farms. Liquid waste is stored on site in a lagoon and pumped out to hay and grain fields for use as a fertilizer. The total cost of construction was $2.75 million dollars with $755,000 of that coming from grants so that Green Mountain Dairy had to invest almost 2 million dollars to build the digester. A second generator was installed six years later with $130,000 of funding support from a state grant. Mr. Rowell self-reported that his farming operation provides 1.8 million kWh to the public grid per year with a constant feed of 40,000 gallons of manure (and sometimes food waste) per day. His biodigester also has an air stripper that removes up to 70% of nitrogen that would otherwise escape through gaseous emissions. Although currently his digester does not include a Phosphorous Recovery System offered by DVO, during an interview he said he is planning to incorporate it into his system when possible. This addition will separate out 75-95% of the phosphorous that enters the system and make it available for more precise application to fields or for sale (DVO Incorporated, 2015). Mr. Rowell reported a yearly maintenance cost of about $80,000.

The energy generated on site is sold back to the grid at a rate of $0.141 per kWh through a 20 year contract in the SPEED program with an additional $0.04 cents per kWh for the renewable energy credits paid through the Cow Power program. Mr. Rowell reported no additional money or credits from state or federal entities.

The site visit to Green Mountain Dairy occurred on February 17th 2015 on an exceptionally cold but sunny winter day. The smell of animals was apparent but not overpowering, a point reinforced by Mr. Rowell as he commented on his improved relationship with neighbors on this point. The dairy was well organized and clean. A tour was given of the calving barn and the heifer barn (a heifer is defined as a young female cow who has not given birth) as well as the milking parlor and the building containing the machinery to run the digester. Although the farm is classified as a LFO there were, it seemed, very few people on site to run the operation and all were involved with feeding and milking the herd. Mr. Rowell said that at most he or an associate will spend two hours per day working with the digester. Mr. Rowell's farm has won numerous awards for land stewardship and product quality. It was clear that in relationship to his land, herd, and employees, Mr. Rowell conducted himself honorably and with care paid to the stewardship of his land, community, employees, and livestock. This is worth noting because he was one of the pioneering members of the Cow Power Program and is a leader in the dairying community in Vermont which suggests that the commitment of early adopters can be crucial to the success or failure of these types of projects. Please see Appendix 2 for the photo documentation and notes of the site visit to Green Mountain Dairy.

China, Da Pu Port Monitoring Station, and the Xing Wang pig farm

The process of research in China proved more difficult than anticipated. In addition to anticipated obstacles, such as language barriers and concerns with basic transportation to site locations, official approval through the department at Nanjing University and associated organizations was needed to be able to visit and conduct my research. Permission was granted for one supervised excursion with fellow students and scientists to two different areas in the Lake Tai water basin hosted by Nanjing University and the governmental agency overseeing hydrology in Lake Tai; this visit took place from October 21st to October 22nd 2014. Permission was not granted to use or look at any data the agency collected on P or N levels in Lake Tai.

In total, nine months was spent in Nanjing, China working with the Nanjing University School of Environment. During this time, two sites located in the Da Pu River watershed that drain into the Lake Tai drainage basin were selected for the collection of data, both written and photographic. Site one was Da Pu Port Water Quality Monitoring Center located in the Jiangsu province about 96 miles away from the city of Nanjing on the banks of Lake Tai (See Figure 1). This site was located close to the mouth of Da Pu River on the Banks of Lake Tai and was surrounded by fish farms. Although there was not a biodigester at this site, this was an important location to visit because it afforded the only view of Lake Tai during the entire nine months of the research collaboration in China. Additionally, it brought to light just how heavily utilized every square inch of land is along the banks of the lake.

The second site visited was a biodigester located on a commercial pig farm just outside of the small agricultural town of Xing Wang. From this site, in addition to photographic and observational data, basic information was collected on the input, output, energy generation, and other aspects of the construction and maintenance of the facility. This farm was a combination of a working pig and vegetable farm and a tourist destination. It featured a restaurant and hotel as well as event and conference space and a large outdoor recreation area; the working areas of the farm were not usually open to the public. Being associated with Nanjing University, a tour was granted of the biodigester facility by the director himself and I was given supplementary marketing materials. With the assistance of a translator, the director of the facility was

Figure 1. Map of Da Pu Port water monitoring station

interviewed. The farm has about 3,600 pigs of various breeds being raised for meat. It maintains a breeding female population of approximately 300 pigs with an additional 3,300 pigs at varying stages of development. A tour of the pig barns was not permitted. It was reported that the digester uses 25,000 tons of manure per year and produces 6.54 x 10^4 m^3 of gas per year and 690,000 kWh per year. The director self-reported that the biodigester cost 2.5 million yuan to construct plus an additional 3 million yuan for the on-site water purification system and that it was partially subsidized by a 2,780,000 yuan investment from the central government. The company that constructed the biodigester was not identified. The yearly maintenance costs, as reported by the director, is about 314,500 yuan. The digester is used to provide gas for cooking and heat and also provides some electricity. The waste water is used to irrigate the 1000 mu (1 mu = .165 acres) of croplands and 2000 mu of rice paddies. It was said that the government invested in this biodigester and 25 other much smaller digesters in the town to help with economic development.   This data was sufficient enough to enter into the CBA template and serve as a basic model from which to begin discussions on the impact biodigesters may have on the Lake Tai region.

The site visit to Da Pu Port occurred on October 22nd, 2014 with a group of several people including three government employees from the a Jiangsu Environmental Protection Department (JEPD) located in the city of Nanjing, a government official from the nearby city of Yi Xing, a business man, and myself and one other Nanjing University student. My fellow student and a young man working with the JEPD assisted me with translating and asking questions. The Da Pu Port Water

Monitoring Station is located in a small recently built structure and is associated with a school and local leaders in the nearby upstream town of Ding Shu. Ding Shu is considered a large country town that is becoming increasingly industrialized by major industries including textile, ceramic, and smelting. The JEPD was surveying the site with the hopes of building an artificial wetland to mitigate pollutants from flooded areas used for fish farming that drains into the Da Pu Gong River only a short distance from Lake Tai. The site they are examining is small with murky water, duckweed and piles of snails filling the area. The area is surrounded by fish farms and plots of vegetables as far as the eye can see; the ground and water has a lot of plastic garbage present. The water in the Da Pu Gong River looked dirty and murky but there is not a lot of evidence of green algae. A picture of the river from late August reveals that until recently it was distinctly neon-green color (please see appendix 3 for photo documentation). It seems that almost every inch of land is being used; it was explained to me that China is pushing for larger farms and discouraging small farms because larger farms can be more easily regulated (see appendix 3). The visit to Da Pu Port reinforced the severity of the problem that Lake Tai is facing. Clearly a few biodigester projects would only be a small piece of a complete solution.

In contrast to the disorderly and haphazard feel of the fish farms near the Da Pu Port Water Monitoring Station, the pig farm located in the town of Xing Wang was organized, well planned, and clean (see appendix 3). Although this farm is not located on a river it is still within the Lake Tai watershed.

Cost Benefit Analysis

The cornerstone of this research is the development of an interactive CBA tool in MS Excel. The tool requires users to input several independent variables and through a series of calculations, the values for the dependent variables are automatically displayed in designated spreadsheet cells.

In this study the independent variables were type of animal, number of animals, energy production per year, price per kilowatt hour (kWh) sold to the grid, financial benefits, and construction and permitting costs.

Calculating N and P from Livestock

To obtain the estimated yearly output of N and P from livestock, several other calculations must first occur. First, the number of animals on the farm must be standardized into animal units (AU) and then annual estimated manure production per AU calculated. This is a matter of simple division and multiplication; Hearing et al. provides a table that clearly outlines these standardized values which have been abbreviated and reproduced in Table 1 and also included in the CBA tool for the purpose of user clarity (Haering, et. al., 2006).

Table 1. Average animal per animal unit by type.

Animal Unit Conversion	1 AU = 1000lbs	
Type of Animal	Approximate # of Animals per Unit	Annual Manure Production (tons)
Dairy Cow	0.74	15.24
Beef Cow	1	11.5
Swine (Breeding)	2.67	6.11
Swine (Other)	9.09	14.69
Poultry (Layers)	250	11.45
Poultry (Broilers)	455	14.97

So, for example, the dairy farm in Vermont featured in this paper has 1,800 head of cattle, the calculation would be as follows:

$$1{,}800 \text{ Dairy Cattle} \div .74 \text{ AU} = 2{,}432.3 \text{ AU}$$

$$2{,}432.3 \text{ AU x } 15.24 \text{ tons manure per year} = 37{,}070.27 \text{ tons manure per year}$$

Haering et al. also provides the estimated Nitrogen, Phosphorous, and Potassium content per 1000 pounds or gallons (depending on animal type) of manure. Swine and dairy manure must be converted from pounds to gallons, whereas all other animal manure nutrient content is given in pounds; for this, the respective conversion rate is 8.26 and 8.3 pounds per gallon (Schmitt & Rehm, 1992a, 1992b). Once the conversion to gallons is calculated, using the data provided by Hearing et al. on nutrient content per 1000 gallons of manure, the calculations are quite simple. To continue with the above example:

$$(37070.27\text{tons x } 2{,}000\text{lbs/ton}) / 8.3 \text{ lbs/gal} = 8{,}932{,}595 \text{ gallons/year}$$

$$(8{,}932{,}595 \text{ gallons/year} / 1{,}000\text{gal}) \text{ x } 28 \text{ lbs/gallon Nitrogen} = 250{,}112.67 \text{ lbs of Nitrogen/year}$$

In this same manner I estimated annual values for phosphorous and potassium. It is important to point out that although this research paper is not concerned with potassium runoff, it is a nutrient of vital importance to farming and therefore it has been included as a line in the CBA in the hopes that this will be a useful tool for aiding in nutrient management.

Assigning a Monetary value to N and P

The inclusion of this line in the CBA is what differentiates this model from others encountered. While no farmer-friendly tool like the one created here was encountered during research, statistics on the performance of biodigesters and the potential emissions reduction they offer were widely discussed and researched. The method of assigning a monetary value to the social benefits of diverting both the P and N runoff diverted into a biodigester is complicated. Admittedly, the values ultimately used in this paper are probably inexact and do not encompass the total economic, social, and environmental costs of lake and ocean eutrophication caused by the runoff of these nutrients. The establishment of these values, like the valuation of CO2 emissions, would require years of research and scientific collaboration to establish and are beyond the scope of this paper.

As discussed in the background section of the paper, the state of Vermont plans to spend hundreds of millions (if not billions) of dollars over the next 20 years to reduce P runoff into Lake Champlain (Vermont Agency of Natural Resources, 2014). At first there was an attempt to derive a value for P from this information based on the price of an individually proposed project, like a wetlands restoration project, divided by the estimated kg of P the project would divert from Lake Champlain thus giving the price per kg of P that the state was willing to spend on P reduction. Although this calculation would prove interesting on many levels (consistency of valuation of P between projects, over or under valuation based on economic benefit of Lake Champlain, etc.) the research value generated would be too regionally specific to generalize for a publishable tool. It was ultimately decided to link the price of N and P diverted from runoff to the established global market price for N and P as fertilizers. According to a report issued by the company Informa Economics for the Innovation Center for U.S Dairy in 2013, the price per ton of N on the global market is approximately $1,411 and the price per ton of P is about $2,984 (Informa Economics, 2013). The justification of using this as a valuation metric is strengthened for two reason. First is the fact that much of the waste water that is left over from a biodigester system is applied as a fertilizer on site and therefore reduces or eliminates the costs of purchasing additional fertilizers. Second, the trends in biodigester technology are developing towards creating systems that ultimately separate out both N and P from the waste slurry into salable commodities. However, although these values will only be used to discuss the results in this paper, the CBA includes lines for additional social costs of P and N with the understanding that as research advances they will be useful and necessary.

Calculating Emissions from Livestock

For this line in the CBA it is necessary to calculate approximate CH4 and N2O emissions per animal head per year. Owen et.al (2014) present an estimate of 8.615 Tg CO_2 equivalent for total methane emissions and 0.678 Tg CO_2 equivalent (CO_2 e) for total nitrous oxide emitted by the dairy industry in California in 2009 from a population of 1,840,000 dairy cows (Owen et al., 2014). The International Panel on Climate Change (IPCC) has estimated that 1kg of CH_4 has 34 times the global warming potential of CO2 and N_2O has 298 times the potential (IPCC, 2013). The calculation for methane emissions per animal (hd) is as follows:

$$1\text{kg CH4} = 34\text{kg CO2 e}$$

$$1\text{Tg} = 1{,}000{,}000{,}000\text{ kg}$$

$$8{,}615{,}000{,}000 \text{ kg } CO_2 \text{ e/yr} \div 1{,}840{,}000 \text{ hd} = 4{,}682.06 \text{ kg } CO_2 \text{ e/hd/yr}$$

$$4{,}682.06 \text{ kg } CO_2 \text{ e/hd/yr} \div 34 \text{ kg } CH_4 \text{ } (CO_2 \text{ e}) = 137.71 \text{kg } CH_4 \text{ hd/yr}$$

So if we continue the example from above using the Green Mountain Dairy in Vermont, the 1,800 dairy cattle emit approximately 247,874 kg CH_4/year, equivalent to 8,430,000 kg CO_2 per year. To calculate annual N_2O emissions the same equation as above was used substituting the CO_2 equivalence of 34 for CH_4 with 298 for N_2O (IPCC, 2013). This yields a value of 1.24kg N_2O/hd/yr and leaves our example of Green Mountain Dairy with a total N_2O emissions estimate of 2226 kg N_2O/yr or 663,000 kg CO_2 e. This puts the total CO_2 e emissions for Green Mountain Dairy at 9,093,000 kg CO_2 e per year.

Owen et. al. also provides a table summarizing the total CH_4 and N_2O emission in 2010 for beef cattle, swine, poultry, and other domestic farm animals in California but excludes their estimated population size (Owen et al., 2014). Therefore, creating the equations to calculate emissions from swine and the other livestock included in the CBA required reference to the 2012 Agricultural Census published by the National Agricultural Statistics Service division of the USDA (USDA NASS, 2012). Although the statistics given by the USDA were from 2012 and the emissions rates for each animal species provided by Owen. et. al were for 2010, for the purposes of this CBA, the comparison will be an adequate estimation until further research yields a more accurate total. So, for 2012, California had a reported herd size of 111,893 swine (USDA NASS, 2012), emitting approximately 0.1058 Tg CO_2 e CH_4 and 0.00284 Tg CO2 e N_2O (see Table 2 for results for all animal types) (Owen et al., 2014). Using the equation above, annual per head emissions of CH_4 and N_2O for swine is, respectively, 9.43 kg (321 kg CO_2 e) and 0.09 kg (25.4 kg CO_2 e).

Table 2. Approximate CH_4 and N_2O emissions by type of animal per head per year in kg.

Emissions from Manure type	CH4/head/year kg	Nox/head/year kg
Dairy	137.7	1.237
Swine	9.431	0.085
Poultry	0.050	0.0027
Beef	1.296	1.616

Assigning a monetary value to emissions averted

The EPA provides a summary of the social cost of carbon, which is an estimate of the economic damages caused by increases in CO_2, published by the Interagency Working Group on Social Cost of Carbon mandated by the United States Government (see Table 3) (U.S. Environmental Protection Agency, 2015b).

Table 3. Social Cost of Carbon – EPA.

Social Cost of CO2, 2015 - 2050 (In 2014 dollars, per metric ton CO2)				
	Discount rate and Statistics			
Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2015	$ 12.00	$ 40.00	$ 62.00	$ 117.00
2020	$ 13.00	$ 47.00	$ 69.00	$ 140.00
2025	$ 16.00	$ 51.00	$ 76.00	$ 150.00
2030	$ 18.00	$ 56.00	$ 81.00	$ 170.00
2035	$ 20.00	$ 61.00	$ 87.00	$ 190.00
2040	$ 23.00	$ 67.00	$ 93.00	$ 200.00
2045	$ 26.00	$ 71.00	$ 99.00	$ 220.00
2050	$ 29.00	$ 77.00	$ 106.00	$ 240.00

The default discount rate that is used in the CBA worksheet is 5%, therefore the price of CO_2 is set at the 2015 5% rate of $12.00 per metric ton. These variables can be easily modified in the CBA model to reflect the desired discount rate. However, prior to assigning a monetary value to CO_2 e, kg needs to be converted to metric tons. This is accomplished by adding the total CO_2 e for CH_4 and for N_2O and multiplying by the conversion rate of .001 (1kg = .001 metric tons). Therefore, the 1800 dairy cows Green Mountain Dairy produce about 9,093 metric tons. Using a 5% discount rate in 2015 and \$12.00 per metric ton/CO_2, the 1,800 cows create \$109,091 worth of damaging GHG per year.

Potential Energy Calculation vs. Actual Energy Generated

Not all the potential energy from gas generated by a biodigester is available to be used on site or sold back to the local utility. Currently, the standard range of biodigester efficiency is between 25 -40% (Cuéllar & Webber, 2008). This is therefore treated as a variable in the CBA. Large biodigesters have an average efficiency rate of around 34-40% while smaller digesters have closer to a 25% efficiency rate (Cuéllar & Webber, 2008).

Potential energy is calculated by converting kg CH_4 per year to kWh per year. This potentially complicated chemistry problem is accomplished by using the conversion rate of 15.493 kWh per kg CH_4 established by the US EPA's Climate Change Division (U.S. Environmental Protection Agency, 2014). The total energy potential for Green Mountain Dairy therefore is 3,826.927.32 kWh per year. Green Mountain Dairy self-reported producing 1,800,000 kWh per year which equals about 47% of the potential energy. However, Green Mountain Dairy accepts a moderate amount of food waste (primarily from Ben and Jerry's Ice Cream) which has not been accounted for in the generation of CH_4, accounting for the higher than average efficiency rate.

Additional Calculations for the CBA Tool

It is necessary to calculate maintenance and labor costs incurred per year. The Penn State Extension at the College of Agricultural Sciences estimates that the average biodigester project requires about 1.5 hours of maintenance per day by a worker paid minimum wage (Homan, 2015). The current federal minimum wage is $7.25/ hour; this equals a yearly cost of $3,969.38. This equation is only used in the experimental CBA tool as an estimate, actual maintenance costs reported by Green Mountain Dairy and Xing Wang Pig Farm are preferentially used.

Another calculation exclusively used in the CBA tool is revenue generated by the sale of fibrous materials. Informa Economics estimated that a plug flow digestion system is able to recover 9 cubic yards of material per cow per year while complete mix systems can recover 7 cubic yards. These can be sold for $21.75 per ton on average (Informa Economics, 2013). The formula to convert from cubic yards to tons requires an estimate of the weight of a cubic yard of dry cattle manure; the estimate used was 656.1 lbs./ cubic yard (California Department of Resources Recycling and Recovery, 2010).

The calculation of the value of dry manure per cow is:

1 Cubic Foot = 24.3 lbs. dry cattle manure

1 Cubic Yard = 27 Cubic feet

1 cubic yard = 656.1 lbs. dry cattle manure

9 Cubic yards = 5,904.9 lbs. dry manure per cow per year

=2.95245 tons dry material per cow per year

= $64.22 per cow per year with a plug flow system

= $49.95 per cow per year with a complete mix system

Again, the annual value of this secondary product that was provided by Green Mountain Dairy superseded this rough estimation.

As a final measure of comparison, the price of the total construction of a biodigester project based on herd size has to be calculated for the CBA tool. The EPA AgSTAR project has estimated that the cost of installation and materials (excluding energy generation equipment and other possible additions) at $150 - $400 per AU for a covered lagoon style digester and $200 - $400 per AU for a mixed plug-flow digester (U.S. Environmental Protection Agency, 2015a). Using this formula, the cost of construction and materials at Green Mountain Dairy is estimated at $729,730.

The government of Alberta, Canada provides an estimated cost of constructing a biogas electricity generating plant of between $3,700 and $7,000 per kWh which equates to an investment of between $564.60 - $1,068.30 per cow (Government of Alberta Department of Agriculture and Forestry, 2015). The results using this formula as compared to the price of initial construction given by Green Mountain Dairy is almost the same. Mr. Rowell reported a total construction cost of $2,750,000 whereas the Alberta formula would estimate his cost for the electric plant at $1,922,940. When added to the estimated cost of materials and construction, the total cost is $2,652,670, which is quite close to Green Mountain Dairy's reported initial investment.

CBA Modeling

With all of these formulas in place, the CBA tool served to model the estimated cost of a biodigester project and the projected returns based on the number of animals on a farm. Figure 2 (below) shows the first few years of the Green Mountain Dairy CBA and Figure 3 shows the entire 16 year spread of the CBA analysis of Green Mountain Dairy and there 1,800 cattle. On page two of Figure 2, in the years to profitability line, the effects of including environmental benefits become obvious. The proposed CBA tool works in exactly the same manner; Figure 3 shows the different animal types that can be used in this model as well as showing the user the raw amounts of manure, P, N, and GHGs that the farm is estimated to generate per year.

Project Timeframe (years from construction)	2015	2016	2017
Revenue or Cost			
Potential Energy Production (kWh/year)		3,826,927.32	3,826,927.32
Energy Available to Sell to Grid (kWh/year) (Model Capacity)	0	1,800,000.00	1,800,000.00
Quantity of material available(tons/year)	0	37,070	37,070
Potential Productivity of Biodigester (m3 methane/year)	0		
Financial Benefits			
Tax Incentives/ Credits	$ -	$ -	$ -
State incentives (grants/payments)	$ -	$ -	$ -
Federal incentives (grants/payments)	$ 755,000.00	$ -	$ -
Carbon payments/ Renewable Energy Credits (yearly)	$ -	$ 153,077.09	$ 153,077.09
Energy Bill Saving (yearly)	$ -	$ 6,000.00	$ 6,000.00
Energy sold to grid	$ -	$ 253,800.00	$ 253,800.00
Secondary products or Savings	$ 100,000.00	$ 100,000.00	$ 100,000.00
Environmental Benefits			
Nitrogen diverted from water systems (Priced per ton)		$ 70,581.79	$ 70,581.79
Phosphorous diverted from water systems (Priced per ton)		$ 215,238.03	$ 215,238.03

GHG Emissions Averted (CO2 Equivalence price)		$ 109,091.74	$ 109,091.74
Environmental clean-up costs averted	$ -	$ -	$ -
Quality of local water sources	$ -	$ -	$ -
Beauty of Local environment (preserved)	$ -	$ -	$ -
Social benefits			
Reduction in health care costs	$ -	$ -	$ -
Feeling of Satisfaction for doing the right thing	$ -	$ -	$ -
Indoor air quality improved	$ -	$ -	$ -
Benefits	$ 855,000.00	$ 512,877.09	$ 512,877.09
Total Benefits Plus Environmental Benefits	$ 855,000.00	$ 907,788.65	$ 907,788.65
Costs			
Construction of Liquid and gas containment and digestion System	$ 2,750,000.00	$ -	$ -
Construction of Water Purification System	$ -	$ -	$ -
Maintenance	$ -	$ 80,000.00	$ 80,000.00
Labor Costs			
Equipment Costs			
Permitting	$ -	$ -	$ -
Carbon payment reporting	$ -	$ -	$ -
Taxes (?)	$ -		$ -
Total Costs	$ 2,750,000.00	$ 80,000.00	$ 80,000.00
Benefits - Costs	$ (1,895,000.00)	$ 827,788.65	$ 827,788.65

Benefits (excluding environmental) - Costs	$ (1,895,000.00)	$ 432,877.09	$ 432,877.09
Years to Profitability with Environmental Benefits	$ (1,895,000.00)	$ (1,067,211.35)	$ (239,422.69)
Years to Profitability without Environmental Benefits	$ (1,895,000.00)	$ (1,462,122.91)	$ (1,029,245.81)

Figure 2. Year 0-2 of Green Mountain Dairy CBA tool analysis

Financial and Economic Analysis of Green Mountain Dairy Farm in Vermont USA	Discount Rate	# of Swine (breeders)	# of swine (other)	# of Dairy Cattle (Lactating)	# of Poultry (chickens, layers)	# of poultry (Chickens, broilers)	# of Beef Cattle	Total Animal Units		Swine: Estimated total annual production of manure	Dairy Cow: Estimated total annual production of manure	Poultry (layer): Estimated total annual production of manure	Poultry (Broiler): Estimated total annual production of manure	Beef cattle: Estimated total annual production of manure			Total esimated Nitrogen produced per year (lbs): Swine	Total esimated Phosphorus produced per year (lbs): Swine	
	0.05			1,800	0				Tons:	0.00	37,070.27	0	0	0			0.00	0.00	
	Animal Units (AU)	0.00	0.00	2432.43	0.00	0.00	0.00	2,432.43	Gallons:	0.00	8,932,595	n/a	n/a	n/a		Tons:	0	0	Tons:
Project Timeframe (years from construction)	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	Total	NPV
Revenue or Cost																			
Potential Energy Production (kWh/year)		3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	3,826,927.32	61230837.08	
Energy Available to Sell to Grid (kWh/year) (Model Capacity)	0	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	1,800,000.00	28800000.00	
Quantity of material available(tons/year)	0	37,070	37,070	37,070	37,070	37,070	37,070	37,070	37,070	37,070	37,070	37,070	37,070	37,070	37,070	37,070	37,070	593124.3243	
Potential Productivity of Biodigester (m3 methane/year)	0																		
Financial Benefits																			
Tax Incentives/ Credits	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
State incentives (grants/payments)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Federal incentives (grants/payments)	$ 755,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 130,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 885,000.00	$802,846.78
Carbon payments/ Renewable Energy Credits (yearly)	$ -	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 153,077.09	$ 2,449,233.48	$1,580,013.58
Energy Bill Saving (yearly)	$ -	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 6,000.00	$ 96,000.00	$61,930.11
Energy sold to grid	$ -	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 253,800.00	$ 4,060,800.00	$2,619,643.73
Secondary products or Savings	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	$ 1,700,000.00	$1,127,406.62
Environmental Benefits																			
Nitrogen diverted from water systems (Priced per ton)		$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 70,581.79	$ 1,129,308.71	$764,949.22
Phosphorous diverted from water systems (Proced per ton)		$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 215,238.03	$ 3,443,808.46	$2,332,700.15
GHG Emissions Averted (CO2 Equivilance price)		$ 109,091.74	$ 109,091.74	$ 109,091.74	$ 109,091.74	$ 118,182.72	$ 118,182.72	$ 118,182.72	$ 118,182.72	$ 118,182.72	$ 145,455.65	$ 145,455.65	$ 145,455.65	$ 145,455.65	$ 145,455.65	$ 163,637.61	$ 163,637.61	$ 2,081,834.02	$1,367,402.72
Environmental clean-up costs averted	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Quality of local water sources	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Beauty of Local environment (preserved)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Social benefits																			
Reduction inhealth care costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Feeling of Satisfaction for doing the right thing	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Indoor air quality improved	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Benefits	$ 855,000.00	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 642,877.09	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 512,877.09	$ 9,191,033.48	$6,191,840.82
Total Benefits Plus Environmental Benefits	$ 855,000.00	$ 907,788.65	$ 907,788.65	$ 907,788.65	$ 907,788.65	$ 916,879.63	$ 916,879.63	$ 916,879.63	$ 1,046,879.63	$ 916,879.63	$ 944,152.57	$ 944,152.57	$ 944,152.57	$ 944,152.57	$ 944,152.57	$ 962,334.52	$ 962,334.52	$ 15,845,984.68	$10,444,271.39
Costs																			
Construction of Liquid and gas containment and digestion System	$ 2,750,000.00	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,750,000.00	$ 2,619,047.62
Construction of Water Purificatoin System	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Maintenance	$ -	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 1,280,000.00	$ 825,734.82
Labor Costs																			
Equipment Costs																			
Permitting	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Carbon payment reporting	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Taxes (?)	$ -		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.00
Total Costs	$ 2,750,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 80,000.00	$ 4,030,000.00	$ 3,444,782.44
Benefits - Costs	$ (1,895,000.00)	$ 827,788.65	$ 827,788.65	$ 827,788.65	$ 827,788.65	$ 836,879.63	$ 836,879.63	$ 836,879.63	$ 966,879.63	$ 836,879.63	$ 864,152.57	$ 864,152.57	$ 864,152.57	$ 864,152.57	$ 864,152.57	$ 882,334.52	$ 882,334.52	$ 11,815,984.68	$ 6,999,488.95
Benefits (excluing environmental) - Costs	$ (1,895,000.00)	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 562,877.09	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 432,877.09	$ 5,161,033.48	$ 2,747,058.38
Years to Profitability with Environmental Benefits	$ (1,895,000.00)	$ (1,067,211.35)	$ (239,422.69)	$ 588,365.96	$ 1,416,154.62	$ 2,253,034.25	$ 3,089,913.89	$ 3,926,793.52	$ 4,893,673.15	$ 5,730,552.79	$ 6,594,705.35	$ 7,458,857.92	$ 8,323,010.49	$ 9,187,163.06	$ 10,051,315.63	$ 10,933,650.15	$ 11,815,984.68		
Years to Profitability without Environmental Benefits	$ (1,895,000.00)	$ (1,462,122.91)	$ (1,029,245.81)	$ (596,368.72)	$ (163,491.63)	$ 269,385.46	$ 702,262.56	$ 1,135,139.65	$ 1,698,016.74	$ 2,130,893.83	$ 2,563,770.93	$ 2,996,648.02	$ 3,429,525.11	$ 3,862,402.21	$ 4,295,279.30	$ 4,728,156.39	$ 5,161,033.48		

Figure 3. Landscape view of CBA tool

Chapter III

Results

CBA of Green Mountain Dairy's Biodigester

Because Green Mountain Dairy received state and federal grants, it was expected that the biodigester project would be profitable when a CBA was performed with environmental benefits excluded. However, with the addition of the environmental benefits, the profitability of the dairy at the end of 16 years at a 5% discount rate is 60% greater. The CBA tool calculates that on Mr. Rowell's farm of 1,800 cattle the biodigester will divert 84.86 tons of P per year from directly entering the waste stream. With the addition of a Phosphorus Removal system with an average recovery rate of 85%, the farm could potentially capture 72.13 tons of P per year at an annual benefit of $215,238 if sold at current market prices. Nitrogen recovery technology is currently capable of removing about 40% of total collected N by a process that first strips away ammonia gas and then solidifies it by treating it with acids (Informa Economics, 2013; Jiang, Zhang, Zhao, Frear, & Chen, 2010). At Green Mountain Dairy, approximately 125.06 tons of N are produced by the cows every year which, at a recovery rate of 40%, represents an annual benefit of $70,582.

The final environmental benefit considered for Green Mountain Dairy is emissions averted. The dairy produces about 247,874 kg CH_4 per year and 2225 kg N_2O per year which, when converted to metric tons and then CO_2 equivalent, equals 9091 metric tons of CO_2 e per year. In 2015, this equates to $109,092 worth of GHG emissions averted per year which at the end of 16 years, when using the 5% discount rate given by the EPA in table 3, amounts to $2,081,834 in CO2 e averted. The inclusion of these environmental benefits adds an additional $394,912 in value to the project each year, so that the project could pay for itself in 4 years as opposed to 6 years (See Table 4).

Table 4. Summary of the annual environmental benefits imparted by the Green Mountain Dairy biodigester.

Annual Benefits from Environmental Biodigester				
	Total Amount Captured	Cost of Capture per lb.	Market Price of Total	Price of Recoveralbe Materials
Nitrogen (tons)	0.00	$ 7.10	$ -	$ 7,615.74
Phospherous (tons)	0.00	$ 3.61	$ -	$ 31,658.07
CO2 e Offsetts (tons)	553.67	-	$ 6,644.06	$ 6,644.06
Total	-	-	$ 6,644.06	$ 45,917.87

Da Pu Port and Xing Wang Pig Farm Biodigester

Unfortunately, it is difficult to attribute any significance to the data obtained from the CBA performed on this farm. It was not possible to obtain information on tax benefits, sale of secondary products, on site electricity costs averted, and the reporting accuracy in the provided marketing materials was also questionable. Therefore, in this case the profitability of the biodigester project with and without the environmental benefits included cannot be compared. The environmental benefits would, however, contribute an additional $106,375 per year to the project if we use the same values as in the VT calculations (Table 5).

Table 5. Summary of the annual environmental benefits imparted by the Xing Wang biodigester

Annual Environmental Benefits from Biodigester			
	Total Amount Captured	Market Price of Total	Price of Recoveralbe Materials
Nitrogen (tons)	29.14	$ 41,116.40	$ 26,725.66
Phospherous (tons)	26.95	$ 80,431.95	$ 68,367.16
CO2 e Offsetts (tons)	940.19	$ 11,282.26	$ 11,282.26
Total	-	$ 132,830.60	$ 106,375.07

The results from this portion of the research project are unfinished. My survey certainly shows the state government is interested in biodigester projects and investing in alternative energy sources, and that significant environmental benefits that could accrue from biodigester projects. However, the hypothesis that biodigesters represent an economically justifiable method of reducing lake eutrophication around the Lake Tai Basin cannot be examined without better data on biodigester performance and costs, and on the impacts on the ecosystem surrounding the lake.

Results from Other CBA Scenarios

A 300 cow dairy has been considered the minimum number of dairy cows for a viable biodigester project. However, the CBA model indicates an investment into a biodigester breaks even after six years, and then starts generating a profit. In contrast, the biodigester with environmental benefits included becomes profitable after three years. At the end of the 16 year projection, the biodigester project which has considered environmental benefits appears to be 75.32% more profitable than its counterpart.

Taken to the extreme, to be profitable at the end of six years the biodigester that includes environmental benefits only needs input from 19 cows as opposed to 291 without environmental benefits. However, the initial investment for the 19 cow biodigester is only $29,474 which is, at this point, most likely an unrealistic cost for an electrical generation plant given current technology. A consistent trend observed is that no matter the herd size, the number of years to profitability when environmental benefits are not considered never less than six. The payback period remains at three with the inclusion of environmental benefits as long as the herd size exceeds 52.

When pig farms are considered using the CBA tool, the inclusion of environmental benefits appears to be even more profound. A pig farm with the same herd size as the Xing Wang farm begins to turn a profit after year one as opposed to five years without environmental benefits considered. In this scenario the inclusion of environmental benefits predicted the profitability to be 86% higher at the end of 16 years.

Chapter IV

Discussion and Conclusion

It must be stated upfront that the CBA tool created for this study is very clearly in its early stages of development and, as it is now, would prove only of limited usefulness to potential clients. The ultimate goal for the CBA spreadsheet is to continue developing it into a fully functioning tool that can be used to judge the estimated economic benefit of potential biodigester projects when environmental benefits are included. Although at this point the Experimental CBA tool's results are not particularly robust, the results are significant enough to warrant further research. To fully account for the technological options available to farmers from biodigester projects and account for size of farm, animal type, diet, local conditions, local labor costs, and the myriad other costs and benefits exceeds the timeframe of this project and the capabilities of this researcher. However, this CBA tool has the potential to become quite powerful and not only assist farmers who are interested in biodigesters, but also enable them to more deeply understand the environmental impact of their farm and the importance of effective farm management plans and practices.

The research hypotheses were in general supported by even this limited edition of the CBA model developed. Within the limitations of this research, the calculations indicated that: 1) the estimated monetary value assigned to phosphorous will have a significant effect on the bottom line on cost benefit analysis of a biodigester project; 2) that the estimated monetary value assigned to nitrogen will have a significant effect on the bottom line on cost benefit analysis of a biodigester project; 3) and that the potential

CH_4 and N_2O emissions avoided by expanding or adopting biodigester technology will significantly increase the economic justification for initiating and expanding biodigester projects.

However, whether or not they would hold true for an actual small scale biodigester project cannot be satisfactorily answered based on this research. The next logical step is to build several small experimental digesters and closely monitor not only their environmental effects but also the actual financial feasibility of a small project. Therefore, I was unable to adequately test the hypothesis that with the inclusion of environmental benefits in a CBA, it is financially feasible and economically justifiable for smaller dairy and hog farms to participate in the Cow Power program in Vermont. While it may ultimately be true, the data inputs and results of this modeling are not yet able to examine that claim.

Although the increased profitability from including environmental benefits in a CBA is significant, what they ultimately offer a farmer is unclear. More likely in the short term these benefits will inform state and federal officials who are reviewing grant proposals for potential projects. The estimated monetary value for N and P represents an additional monetary benefit by putting a dollar value on pollution that would be avoided. Actually, in its current form, the CBA probably underestimates the value of N and P as additional social and economic benefits have not yet been accounted for. The state government of Vermont has spent approximately 5 million dollars per year since 2006 to reduce phosphorous pollution from contaminating Lake Champlain and they plan to continue and possibly increase that spending (Vermont Agency of Natural Resources, 2014). With further research and collaboration with appropriate agencies, the price

Vermont has been spending per pound P can be determined and added to the CBA. Currently, at an initial investment price of $2,750,000 Green Mountain Dairy is has the potential to remove P at a rate of $19.06 per pound. With further development it will be possible to see if that is more or less than the State of Vermont has been paying. As the CBA tool develops further it is predicted that biodigesters will be perceived as more attractive projects and will attract more financial incentives from state and federal agencies.

Something that is not considered in this research paper is the effect on public and private utilities of having diffuse "micro power plants" throughout their system. There has been much debate in the U.S over the regulation of solar panels and how excess energy should be absorbed and paid for by state governments and utility companies. How an increase in energy generated by biodigesters would affect utility companies is an additional area that would benefit from further research.

Furthermore, it must be said that biodigester technology alone is not a one stop solution to emissions and runoff from farming operations and they are certainly not appropriate in all cases. For example, to remediate the nutrient runoff from fertilizers, farmers would further reduce their environmental impact by dedicating some of their land to a constructed wetland or to preserving an existing wetland. Agricultural ecosystems are complex. The number of variables that may affect nutrient leaching and emissions are vast and difficult to account for in one research paper. Different management variables such as how and when land is fertilized, technology utilized, and animal feed, etc., as well as differences in local conditions (soil type, precipitation, previous use, etc.) all affect runoff and emissions. Agricultural biodigesters are a well-developed technology that offer a very strong first line of defense in the battle to reduce non-point source pollution and the degradation of valuable fresh water resources. This research clearly shows that agricultural biodigesters should be considered not only for their potential to reduce emissions but also for their potential to combat lake eutrophication. I hope this research contributes in some small way to a greater understanding of the possibilities of this fascinating and continually developing technology.

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Appendix 1

Survey sent to farmers after an initial letter of introduction and intent was sent:

Dear *Name of Farm or Head Farmer*,

Please answer as many of these questions as possible with as much accuracy as possible. If you are not sure of an answer please either indicate that the question is being skipped or, if you can, refer me to a person or resource that may have the information. Thank you for your participation in this project, your time is greatly appreciated.

Survey Questions

General:

1. What company designed/built your biodigester (i.e. make and model)?
2. What are its components (for example does it have a water purification system, etc.)
3. What is the projected lifespan of your facility, if known?
4. How many cows do you have on your farm?
5. What breed of cow do you farm?
6. On average, how many are lactating at the same time?
7. How many are calves/sexually immature?
8. Do you keep bulls? If so, how many?
9. What do you feed your herd?
10. Do they free graze at any point during the year?
11. How much, in your estimation, manure is produced per year (in gallons) and/or, what is the manure capacity of your biodigester?
12. How much bio-gas are you producing per year?
13. How many kilowatt hours is your facility producing per year?

Costs:

1. What was the total cost of construction for your biodigester project?
2. How much personal money did you have to contribute?
3. What are your yearly maintenance costs? If they vary each year could you provide an estimate/average?
4. Did you have to pay any permitting fees? Do you have to renew these permits/ pay regular fees of this type?
5. Are there any special taxes that you must pay on your biodigester facility?
6. Fees for any reports or inspections that you must submit?
7. Please list any other costs that I have not asked about

Benefits:

1. What is your yearly income from energy sales?

2. What is your yearly income from sale of secondary products (e.g. fertilizers)? Please also indicate what products are?
3. Please list any state and federal grants that were awarded for the construction of the facility
4. Do you receive any assistance with yearly maintenance costs? If so how much and from who?
5. Any additional awarded money?
6. Do you get any tax incentives/deductions?
7. Do you receive carbon payments or renewable energy credits? If so how much per year?
8. How much does your farm and home save on energy bills per year, if anything?
9. Please list any other financial benefits that were not asked about.

Environment:

1. Before you had the biodigester facility, how did you store the manure on your farm and what did you ultimately do with it?
2. Are there any rivers, streams, small lakes, wetlands, or other bodies of water on or near your property?
3. Has your land changed in any observable way, either for better, worse, or neutral, since the project commenced?
4. Has your relationship with your neighbors changed in any way since the construction of you biodigester facility?
5. Please feel free to tell me any anything else about your facility that you think is pertinent or interesting or that you feel I did not consider in my earlier questions

Thank you very much for your participation! I will be sending you your farm specific results soon.

Sincerely,

Claire Vaterlaus Staby

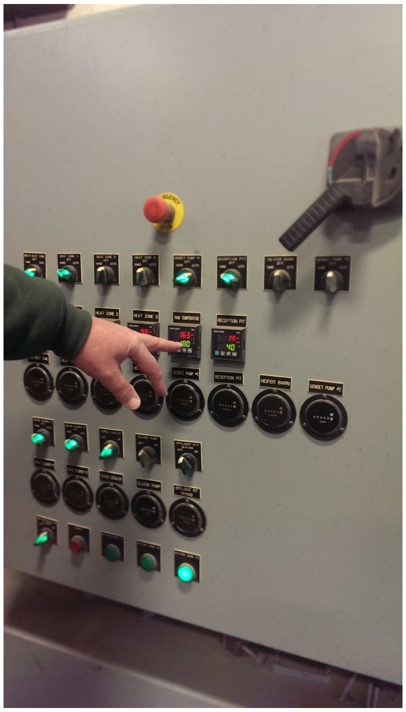
Appendix 2

Green Mountain Dairy
collection tank


Concrete covered


Electric Generator

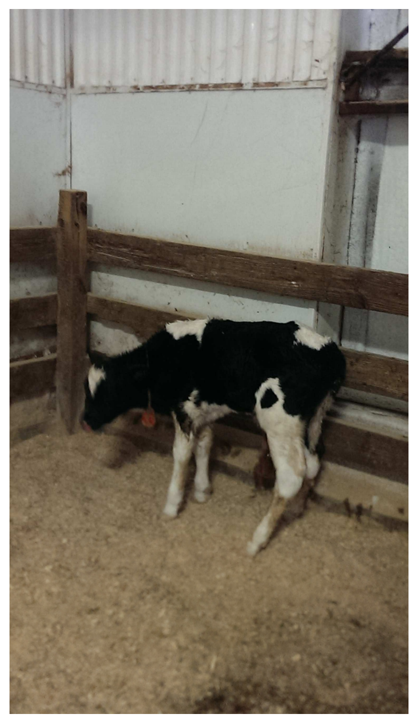

Generator Piping



Control Panel

Recovered Fiber

Dry Feed



Newborn Holstein

Appendix 3

Close-up of Water

Da Pu Port Water Monitoring Station

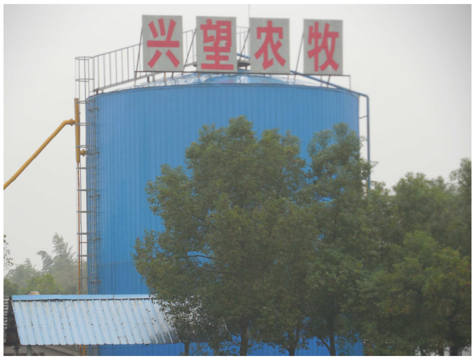
Mouth of river running into Lake Tai

Farming on the river bank

Fish Farm at Da Pu Port

Inside Monitoring Station

Image of river water in August



Xing Wang biodigester

Water treatment machinery

Pretreatment Lagoon

Runaway Pig

Conference Center at Xing Wang

Hotel at Xing Wang